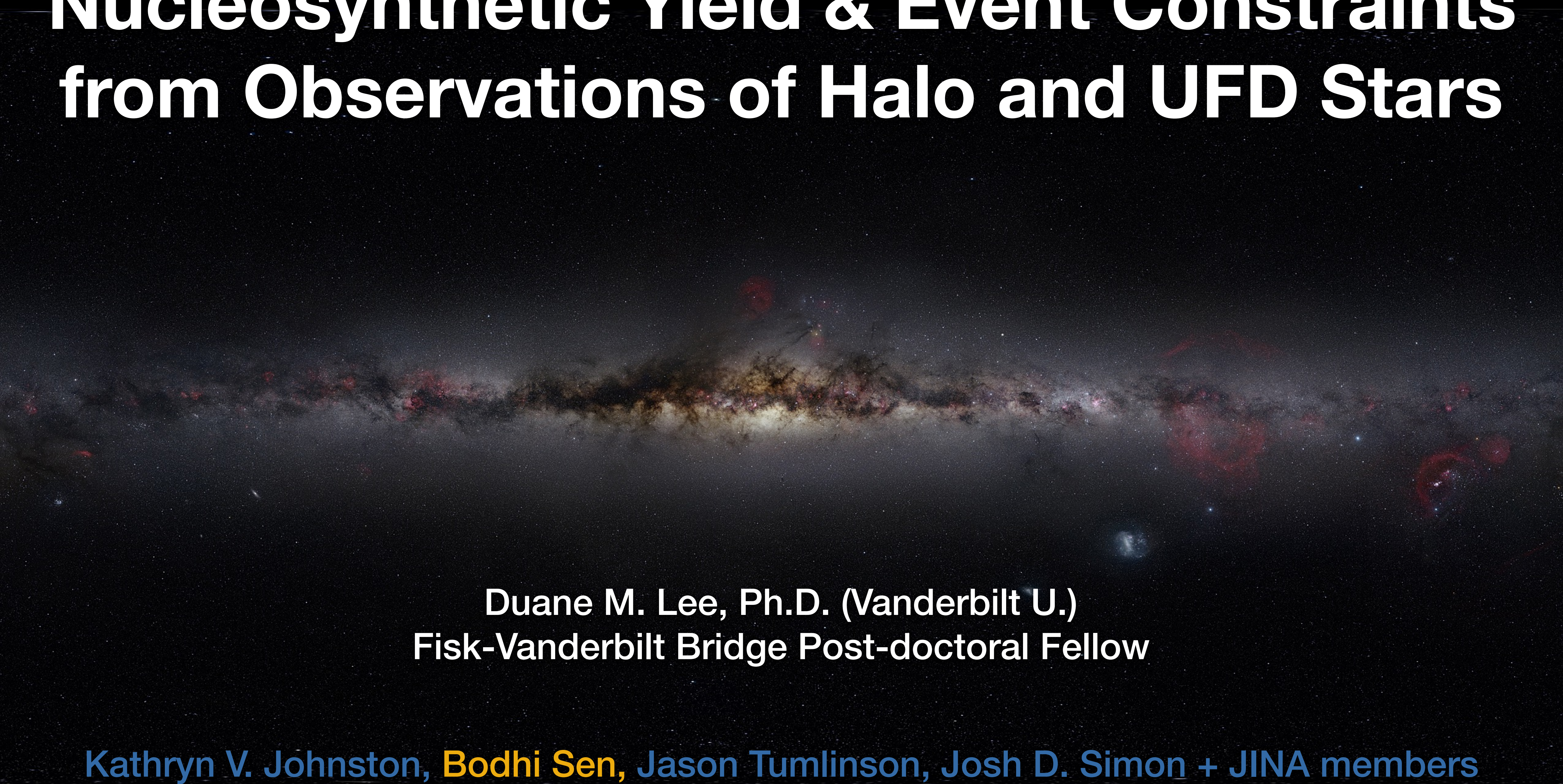
Playing Your CARDs Right: Deriving Nucleosynthetic Yield & Event Constraints from Observations of Halo and UFD Stars



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Kathryn V. Johnston, Bodhi Sen, Jason Tumlinson, Josh D. Simon + JINA members

Statistical Challenges In Modern Astronomy VI, June 10, 2016

Image Credit: Nick Risinger

Overview

Chemical Abundance Ratio Distributions (CARDs)

- CARD modeling vs IMF-averaged GCE tracing and detailed individual stellar abundance measurements
- Examples of CARD analysis
- Applications of CARD analysis to astrophysical phenomena
- Add to some important questions posed by conference organizers and attendees

CARD modeling vs Other Methods

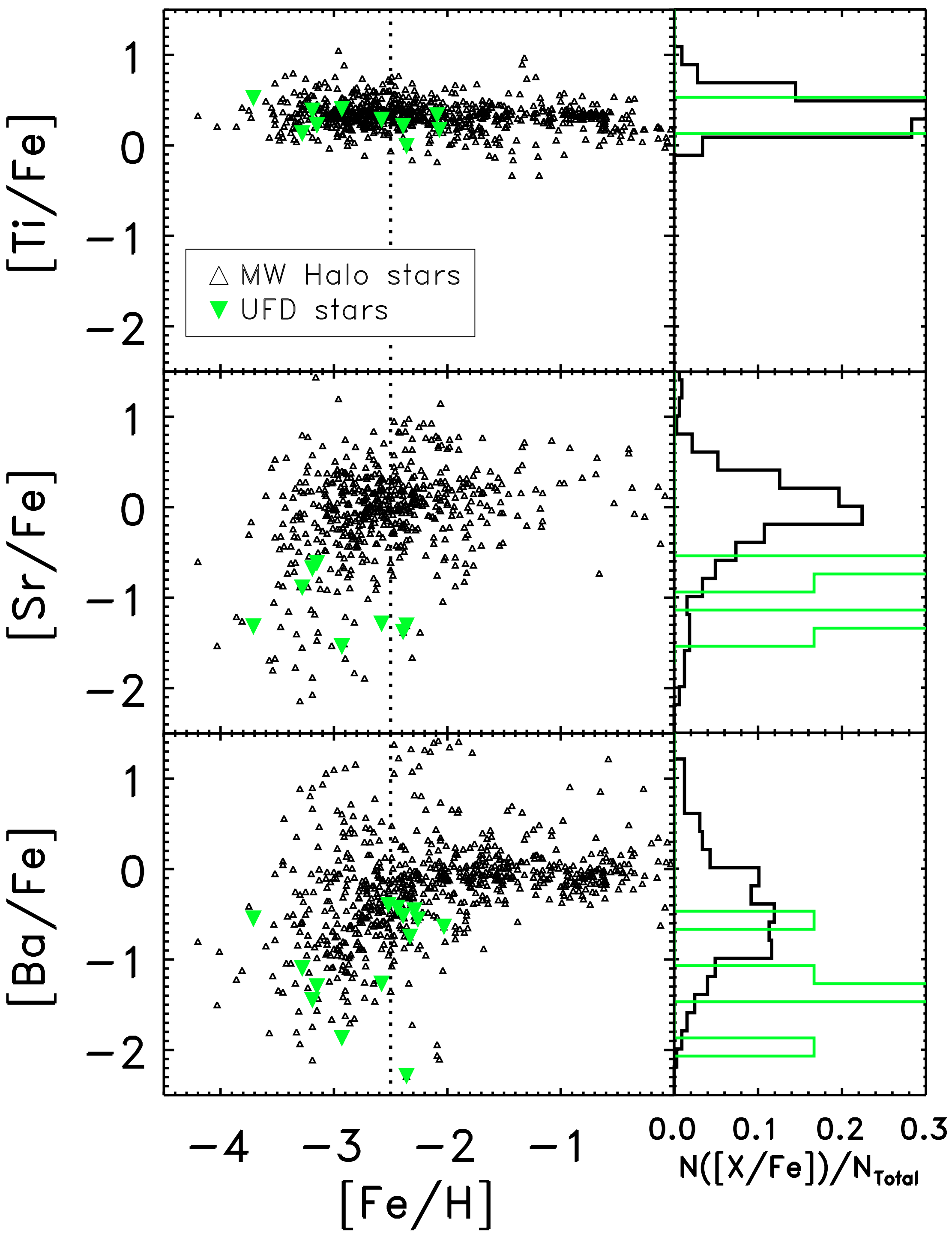
- CARDs reflect the main contributing factor to essentially all stellar progenitors' yields: their mass!
- CARDs can be used to probe the nature of processes that span the whole IMF or portions thereof
- CARD-generating models are robust against by peculiar abundance outliers
- CARD-generating models can leverage substantially more observational data than old, IMF-averaged GCE tracks
- You do not have to speculate about individual stellar enrichment histories like in e.g. detailed individual stellar abundance analysis
- You can marginalize over the yields from individual epochs of stellar evolution or single them out

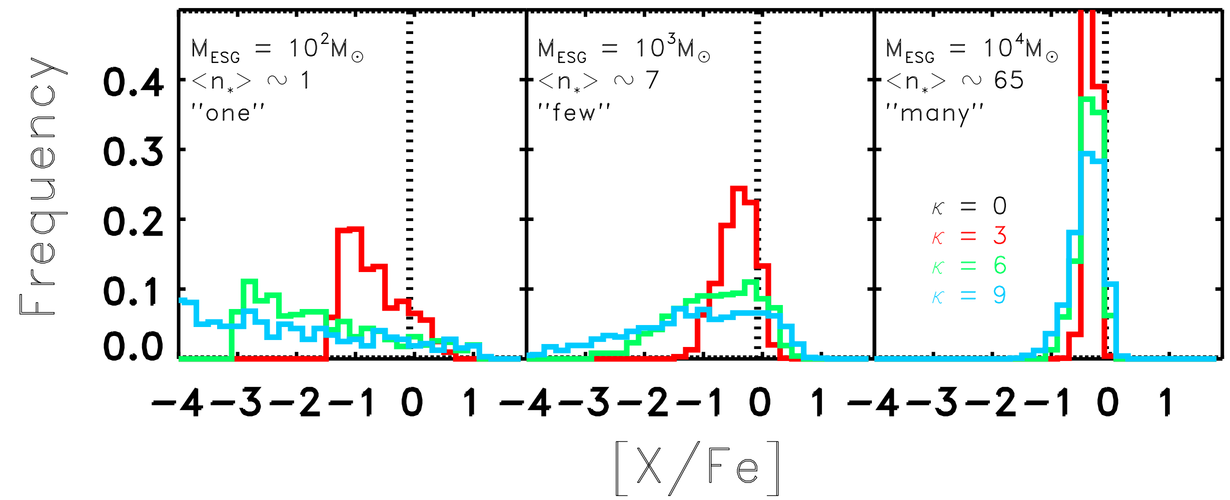
Examples of CARD Analysis

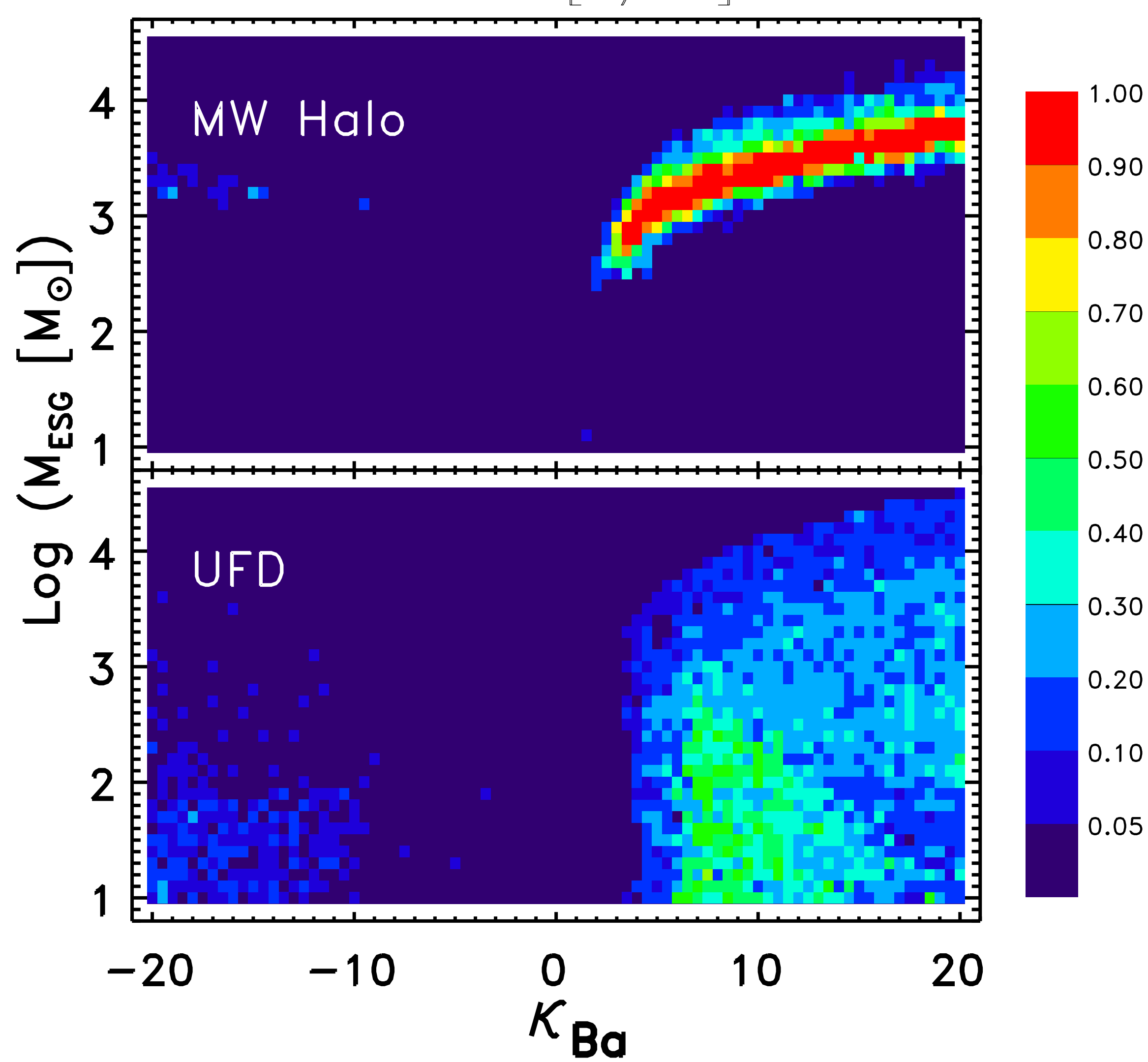
- Lee et al. (2013) - Using CARD models to explain the differences in observed Halo and UFD star CARDs —> constraining yields & sites
- Cescutti & Chiappini (2013) - Qualitative comparison of CARD models to observations to support enrichment from various process including spinstars —> identifying sites & processes
- Schlaufman et al. (2013) - Statistical Chemical Tagging of Observed Halo stars to assess a rough estimate of the relative contributions from Halo star progenitors —> constraining accretion events
- Lee et al. (2015) - Proof of concept study to recover the luminosity function or accretion history profile of simulated MW-like galaxies —> detailed recovered halo accretion histories

Constraining Yields & Sites

Lee et al. (2013)





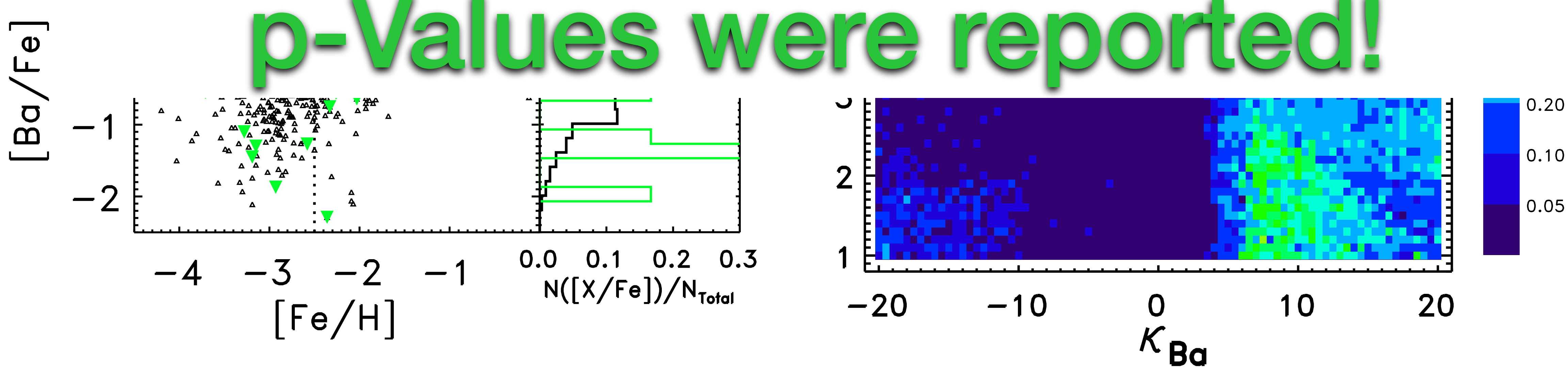


Constraining Yields & Sites

Lee et al. (2013)

Warning: The 2-D KS was used in the making of this paper.

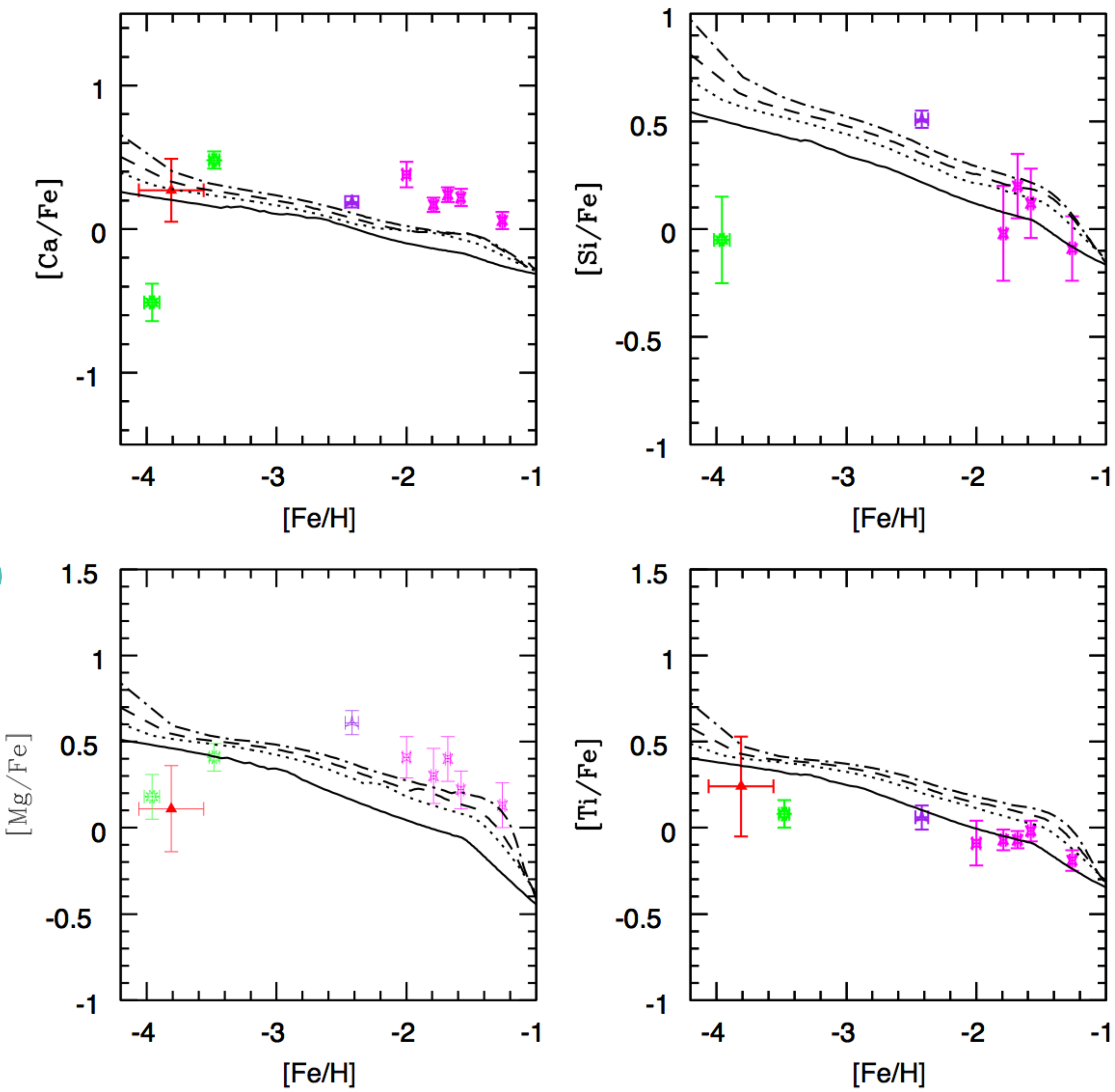
p-Values were reported!



Identifying Sites & Processes

IMF-averaged GCE tracks

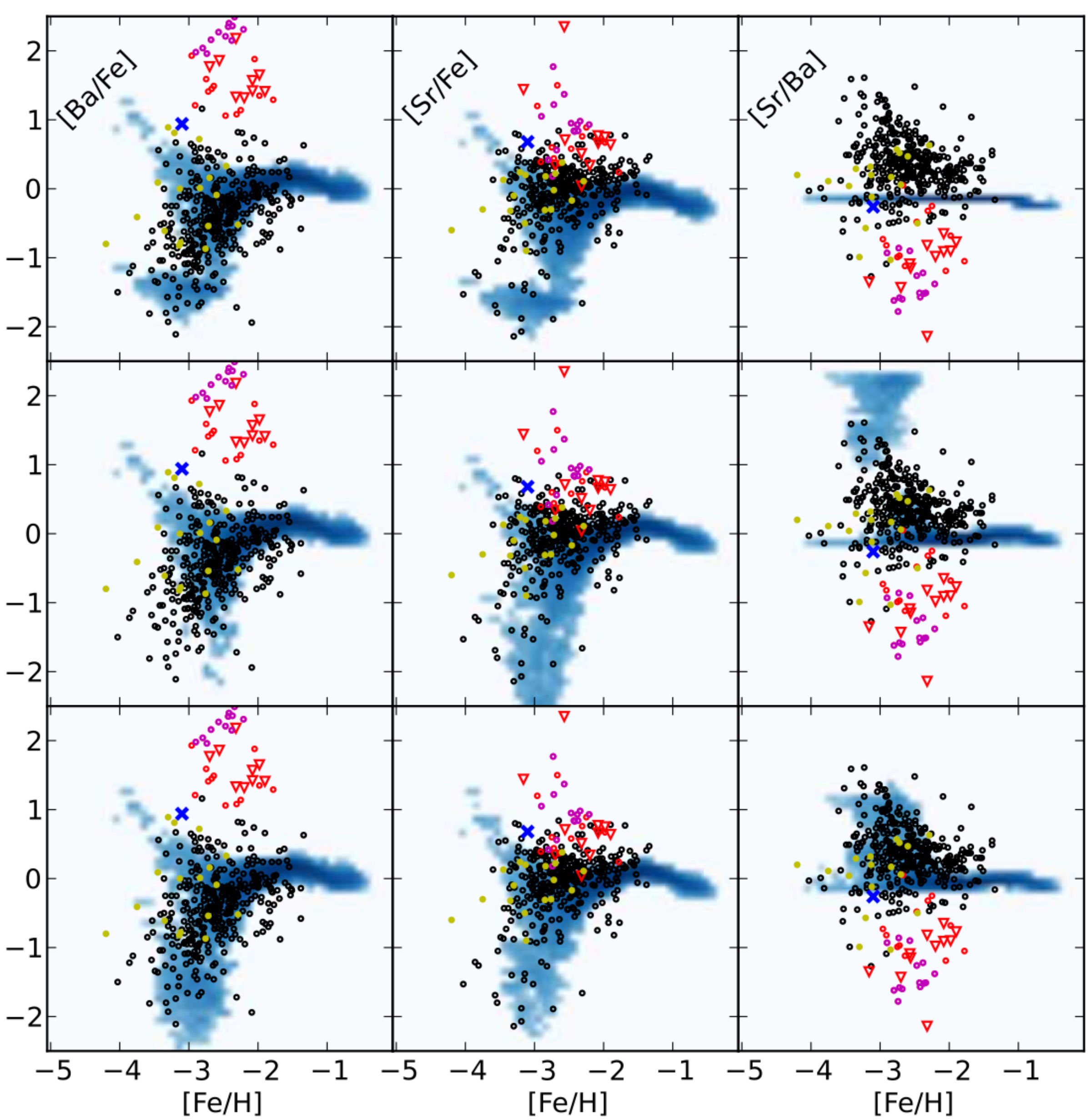
Vincenzo et al. (2014)



Cescutti & Chiappini (2013)

non-rotating

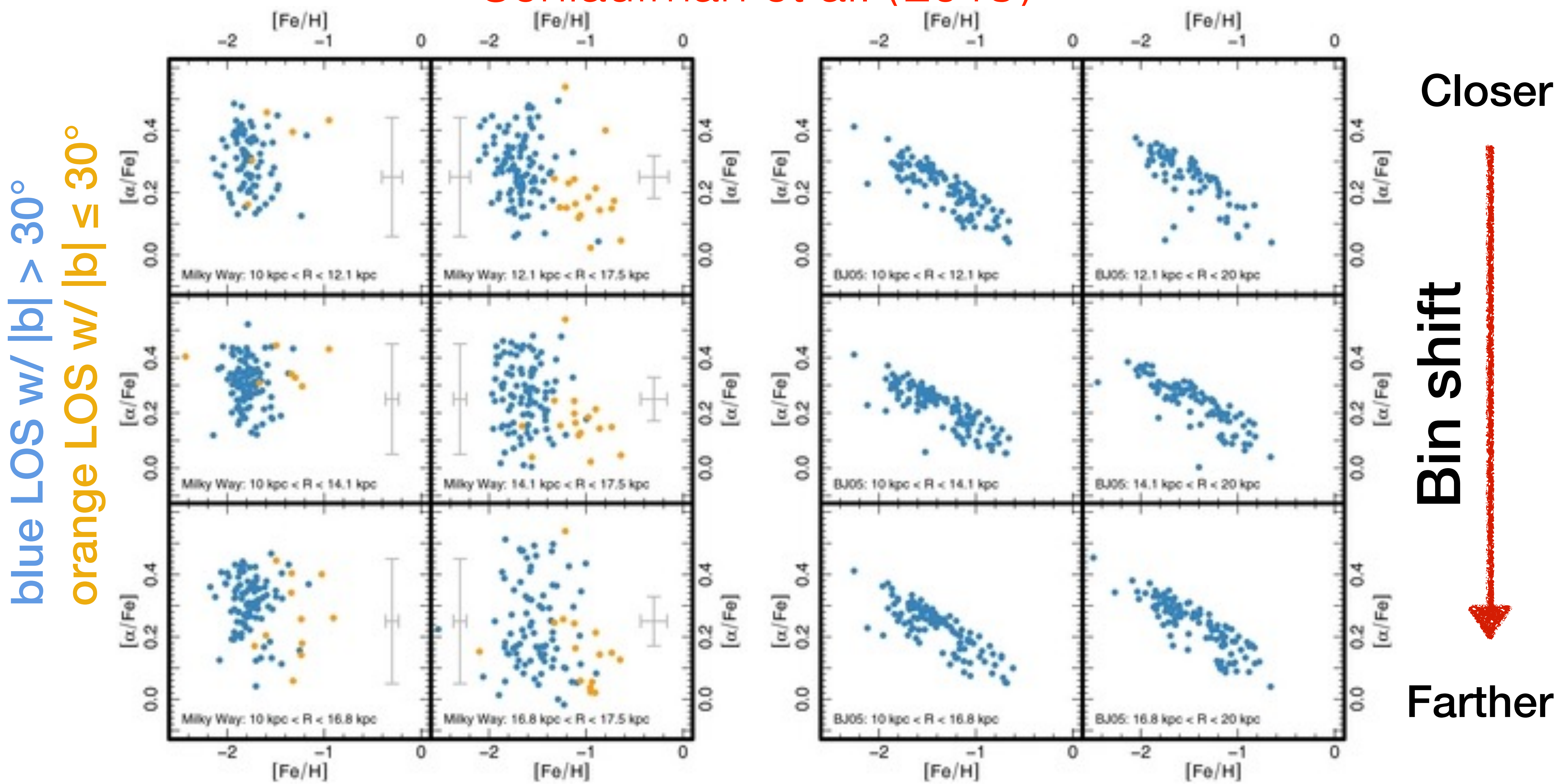
rotating models



- Previous work does not attempt to use CARD densities to work out SFHs or derive n-capture yield constraints

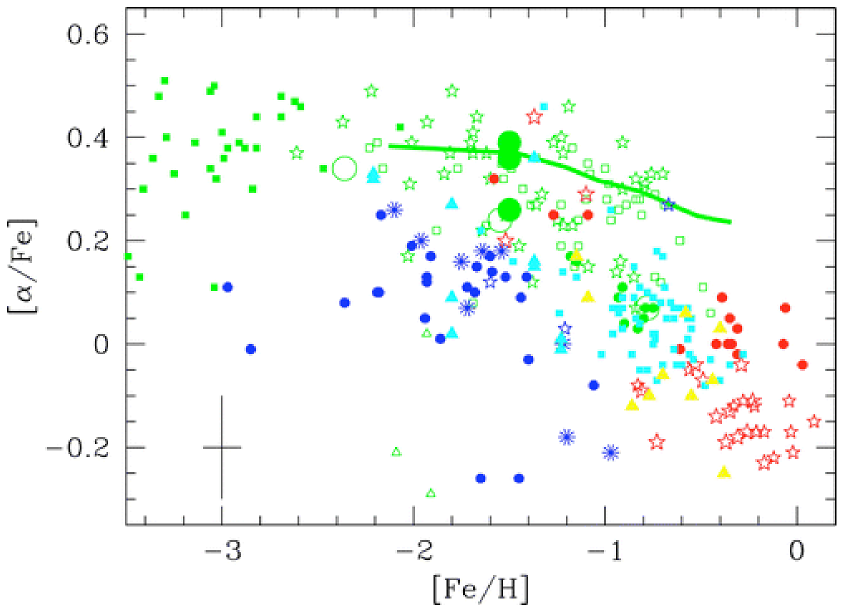
Constraining Accretion Events

Schlaufman et al. (2013)



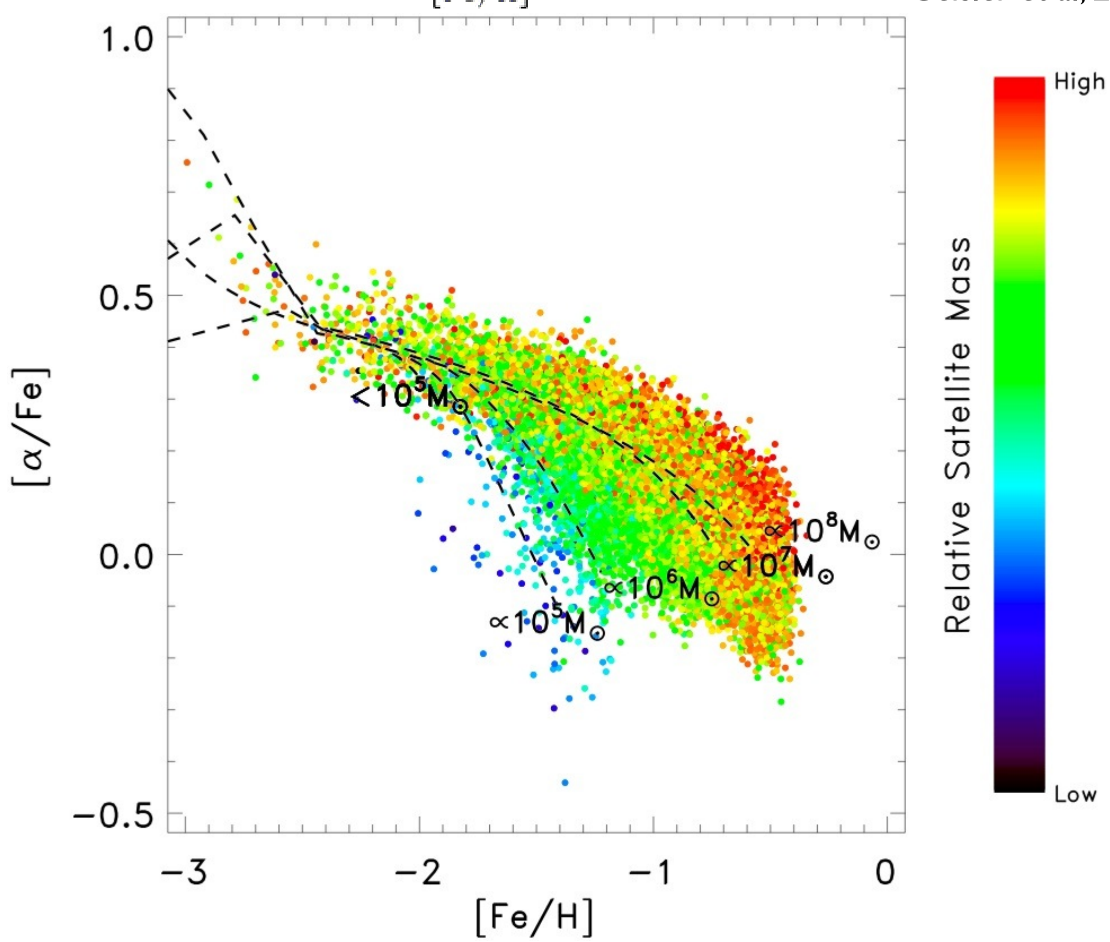
- This work stresses need for better CARD dwarf model templates to work out SFHs or accretion histories — more accurate yields needed!!!

Recovering Halo Accretion Histories



green - halo
blue - low mass dSph
yellow - dIrr
red - Sgr
cyan - LMC

(data compilation from Geisler et al, 2007)



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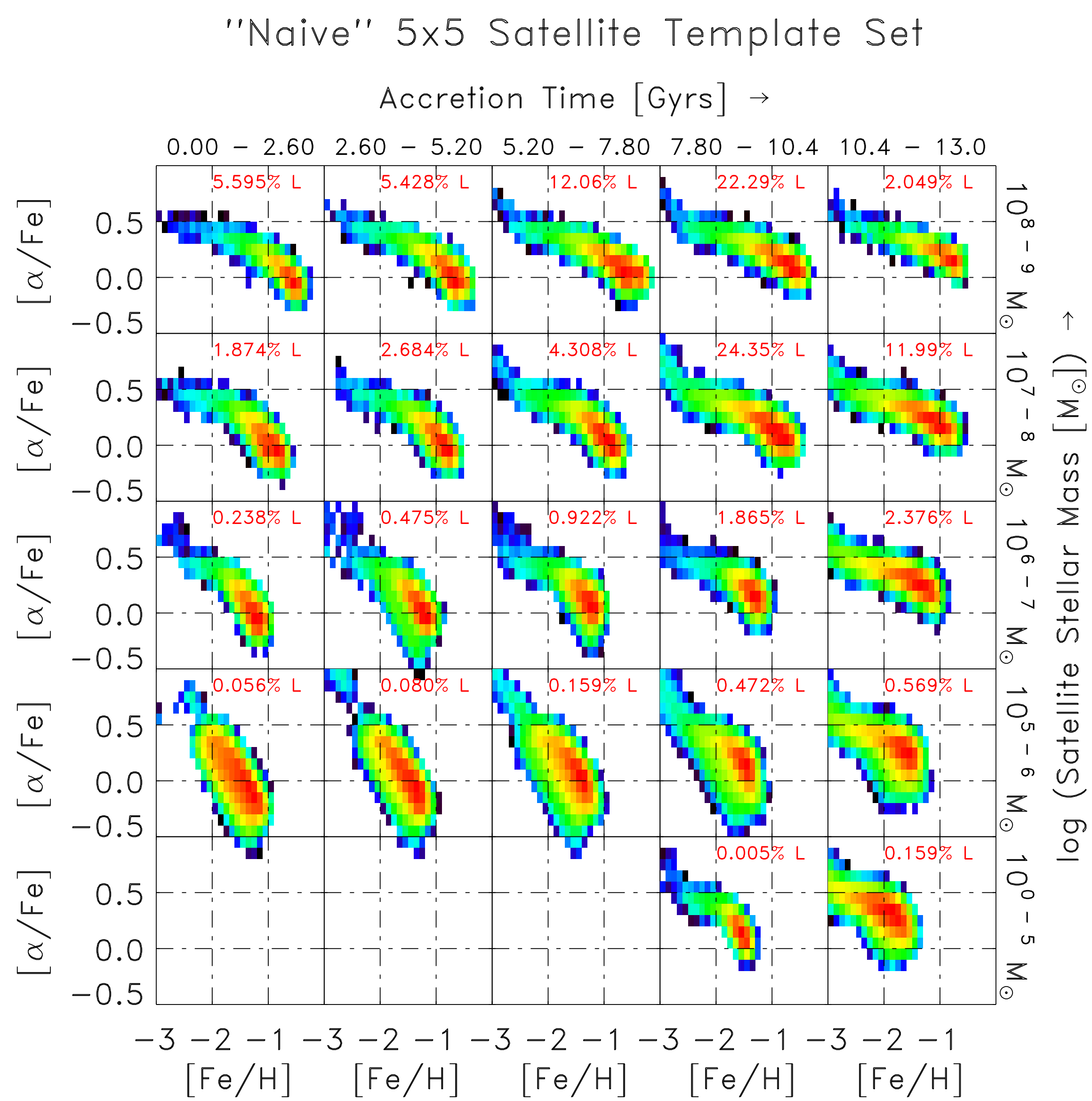

Applications of CARD Analysis

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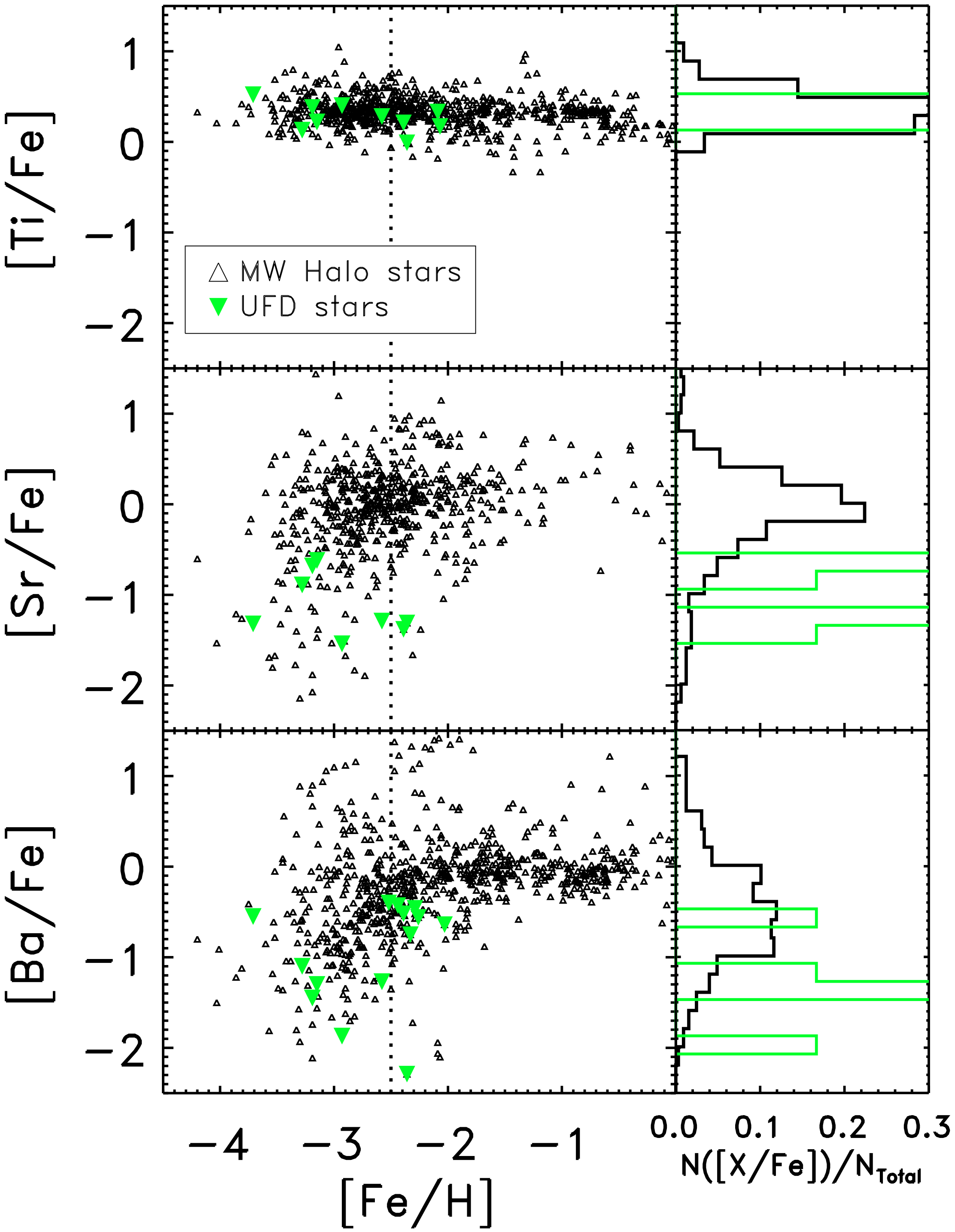

<u>What is needed to fit observations?</u>

- Stochastic Sampling of IMF (Salpeter)
- Stronger MDYs for n-capture elements than for alpha-elements
- Progenitor enriching stellar generations (M_ESG) are more massive for VMP MW Halo stars than for UFD stars

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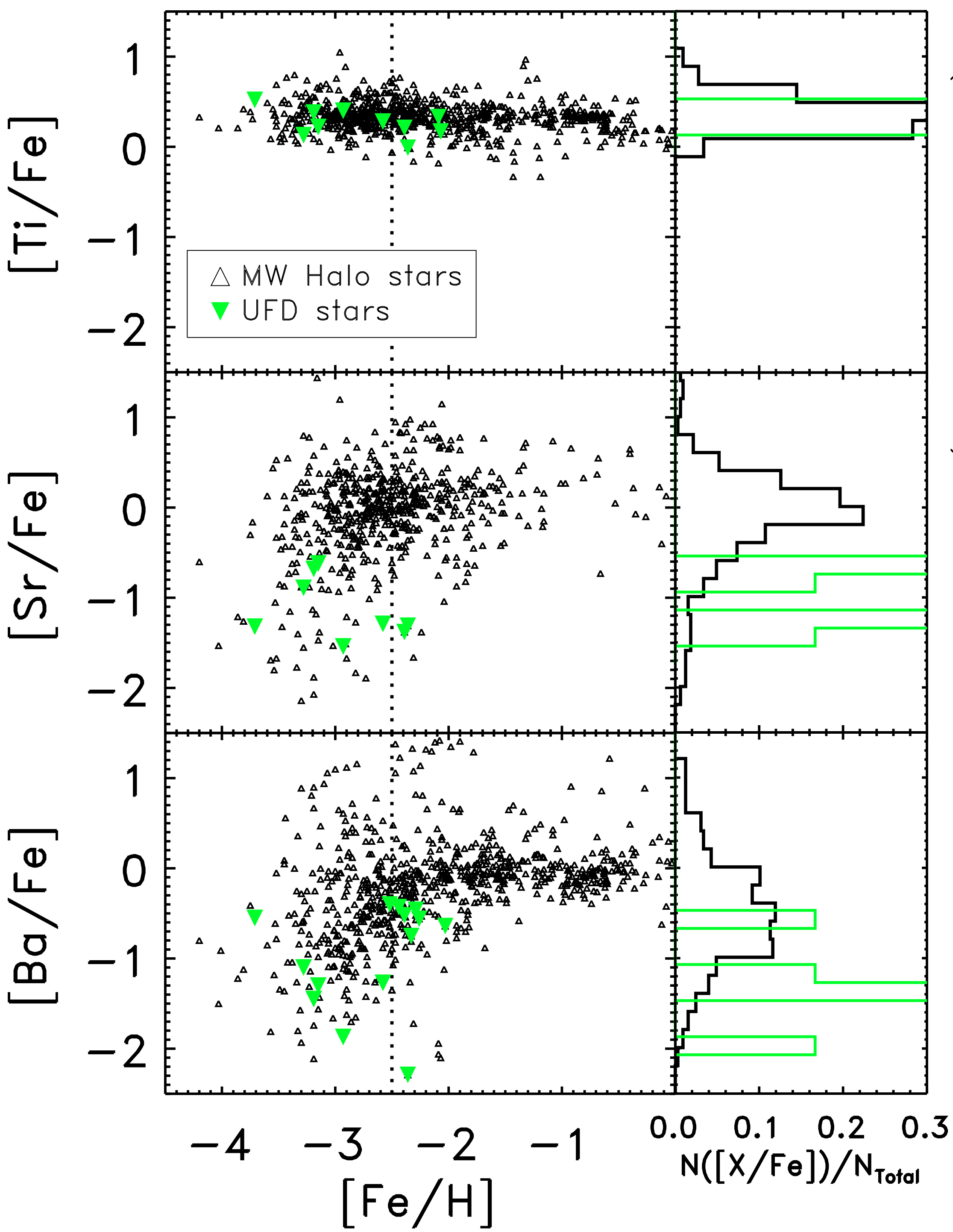

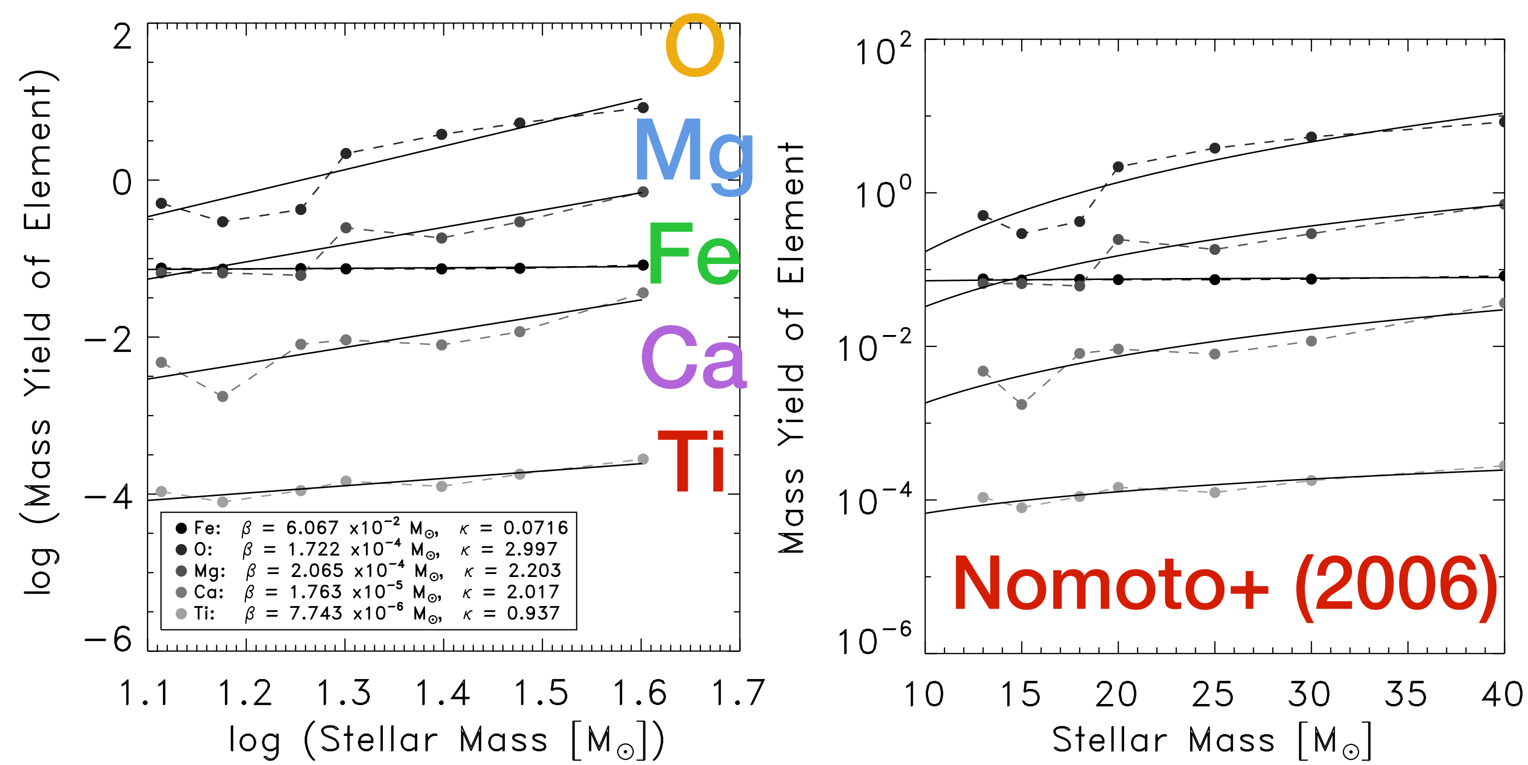

K_x = "strength" of MDYs

Eqn. for MDYs

$$M_x = B_x\,(m\_star)^{K_x}$$

$K_O = 2.997$

$K_{Mg} = 2.203$

$K_{Fe} = 0.0716$

$K_{Ca} = 2.017$

$K_{Ti} = 0.937$

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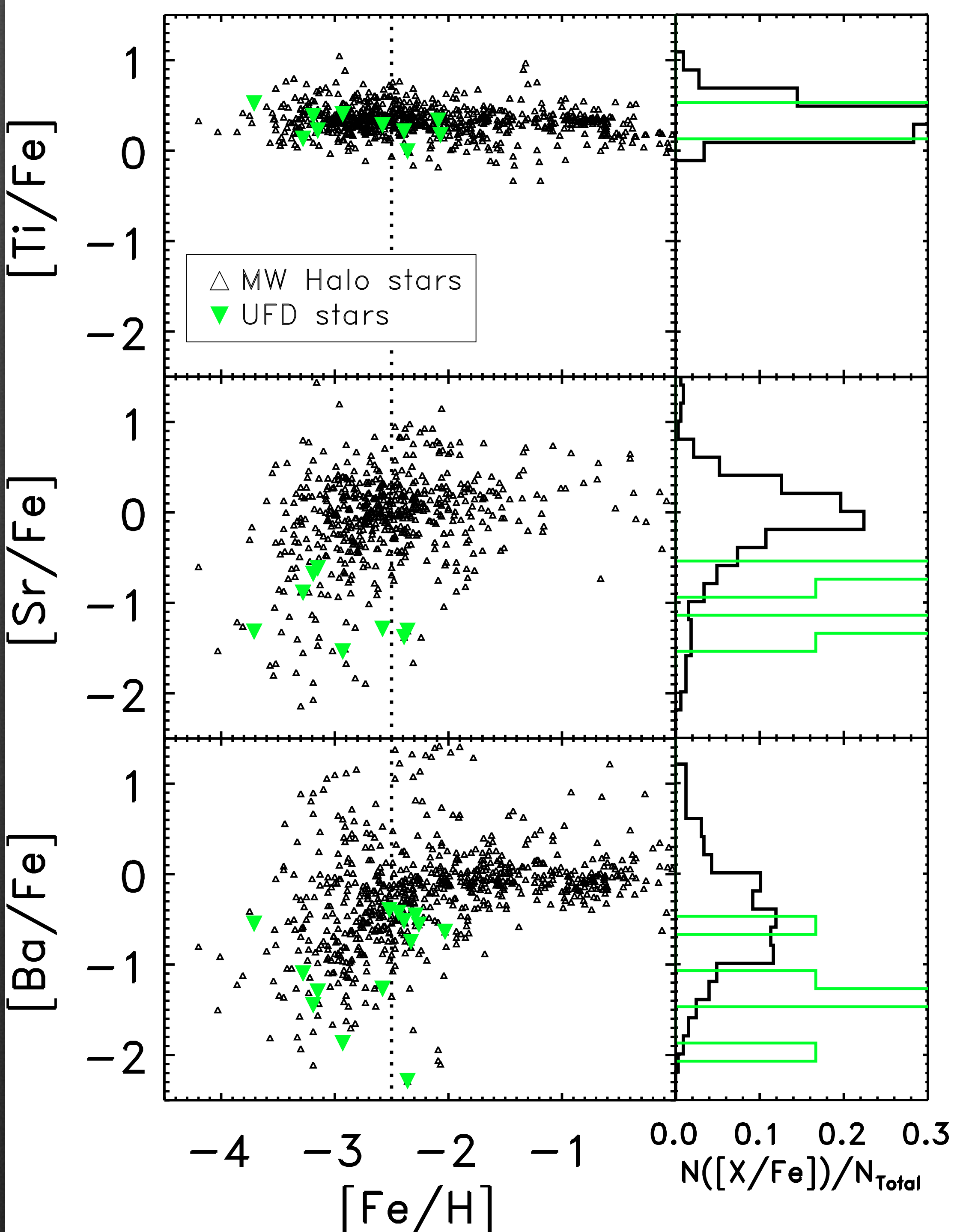

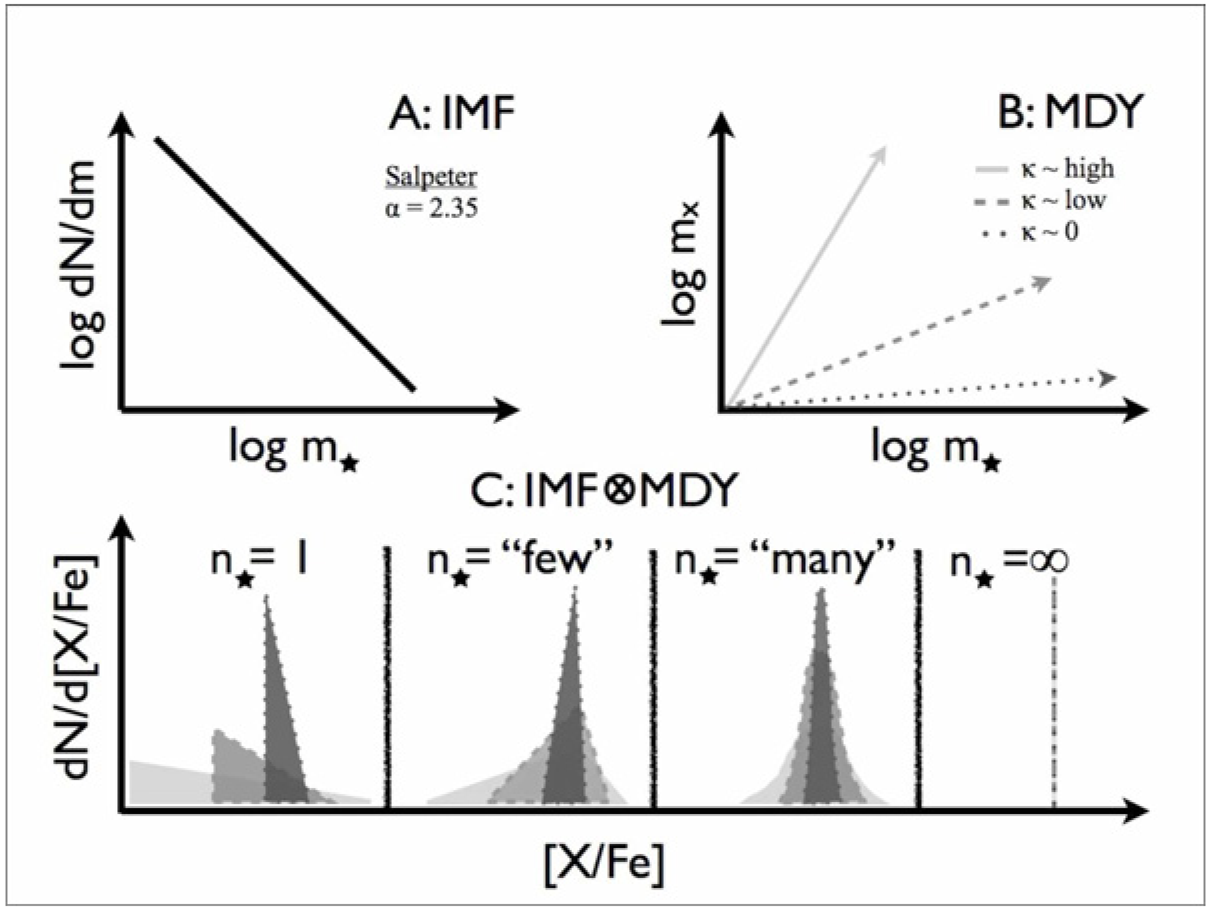

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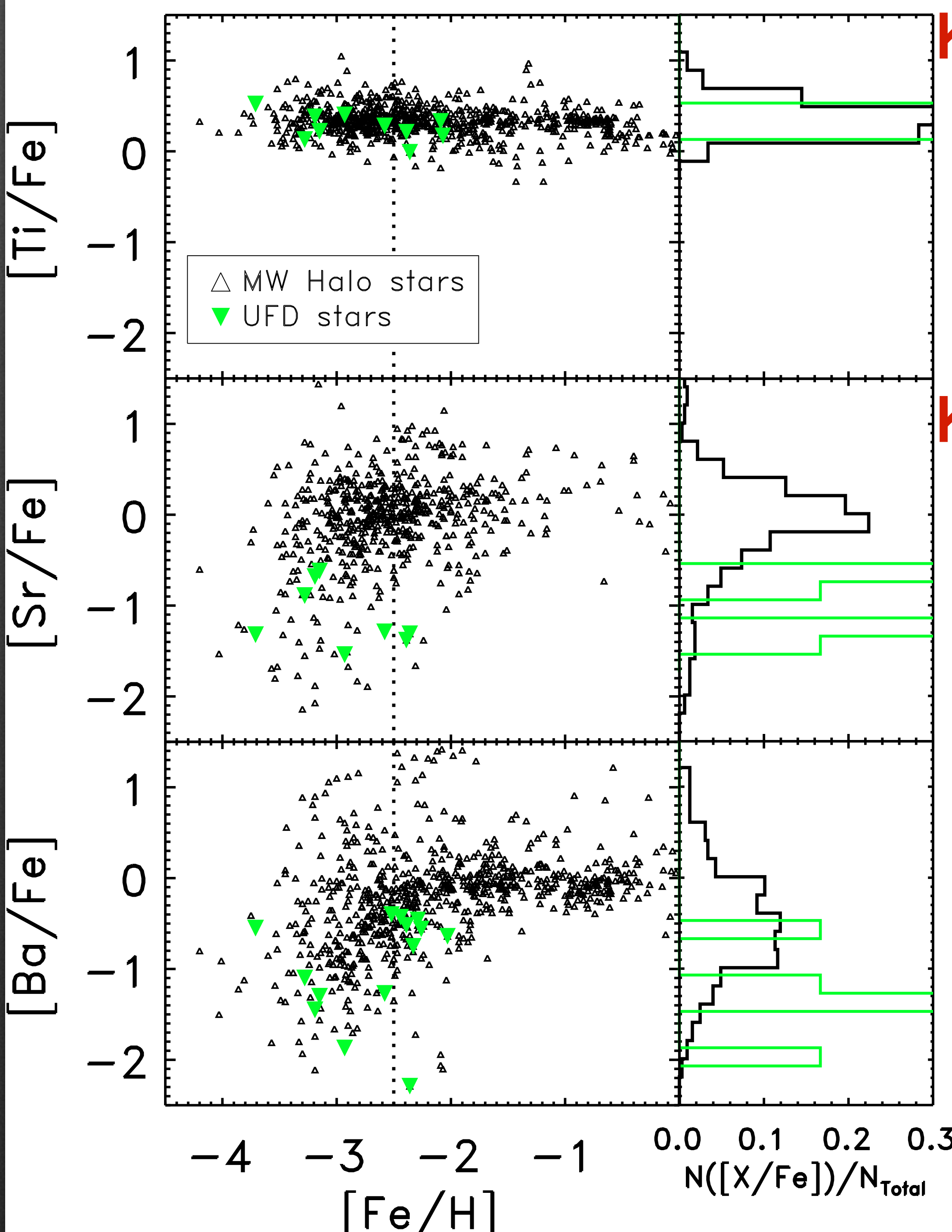

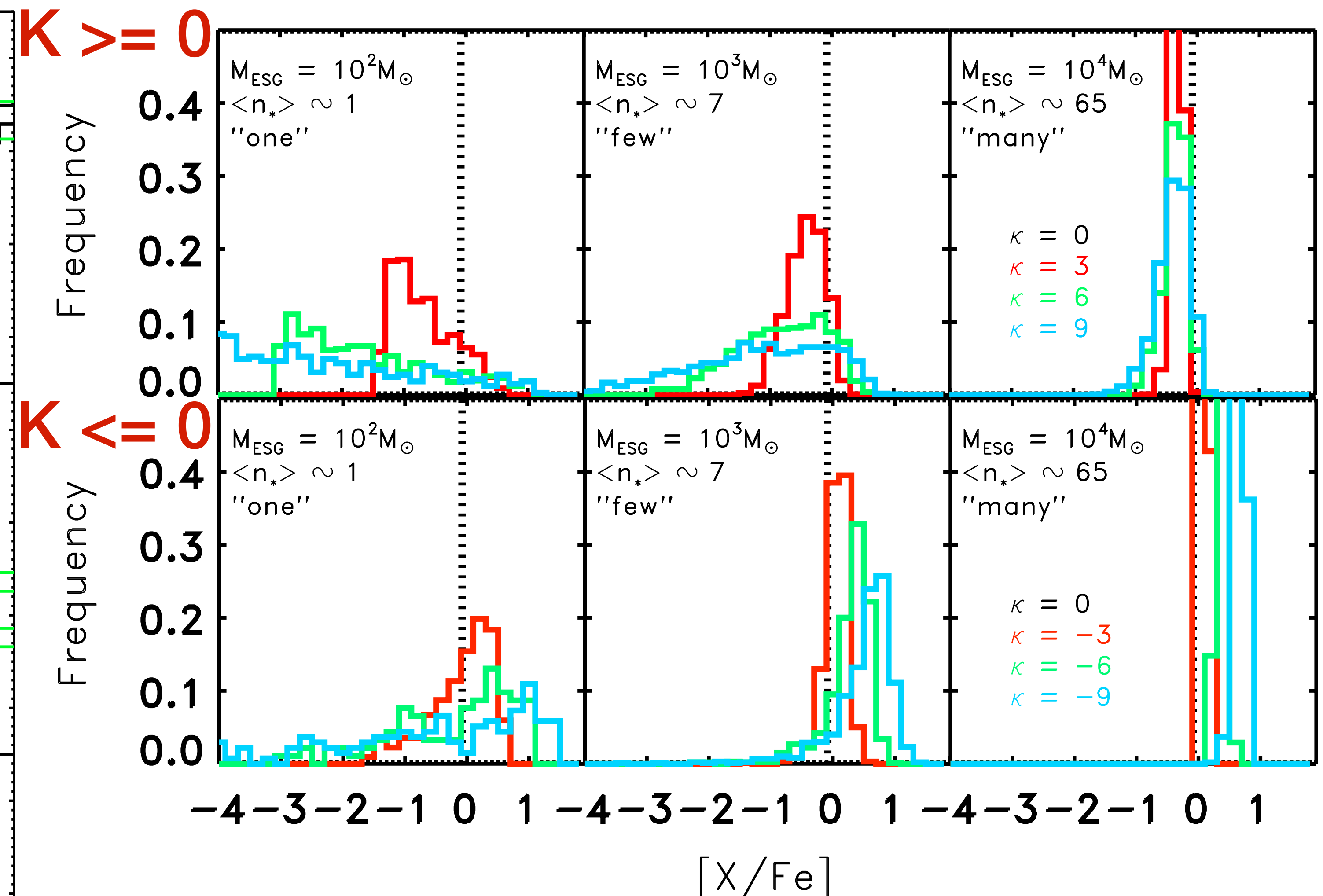

PDF models of 1000 "one-shot" realizations

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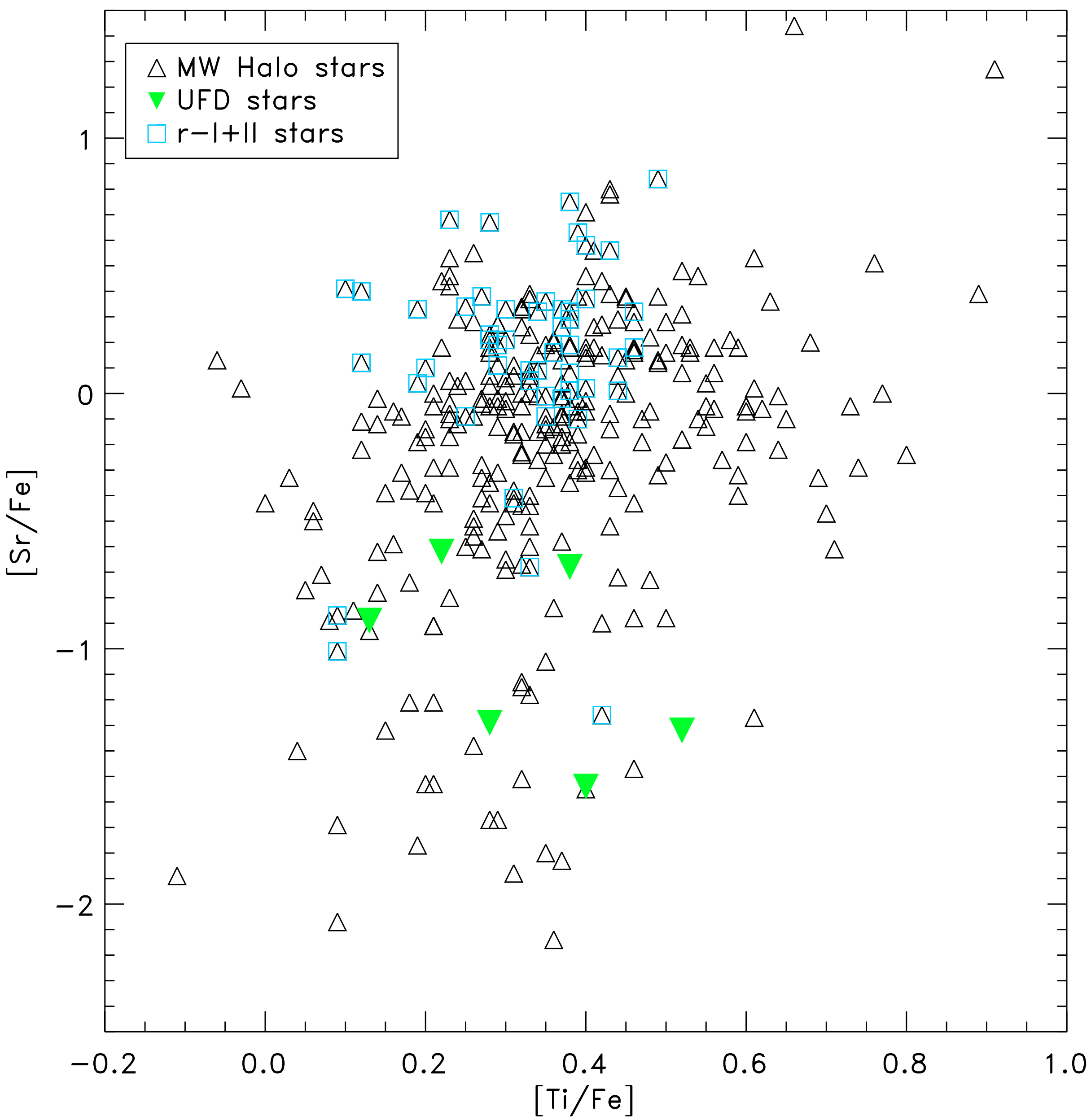

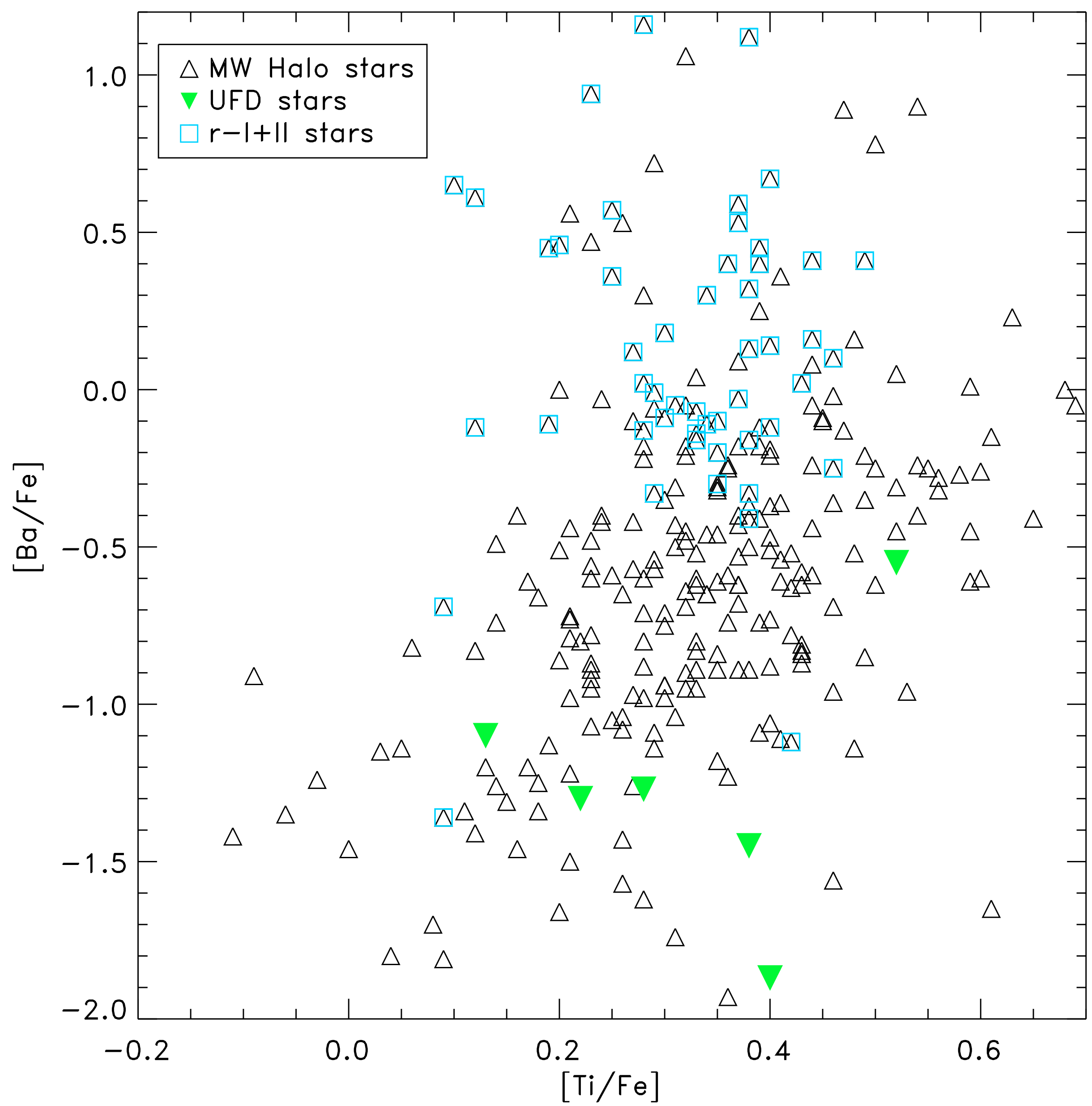

Culled sample distributions from Halo and UFD stars to compare to "one-shot" distribution models (all stars with [Fe/H] < -2.5)

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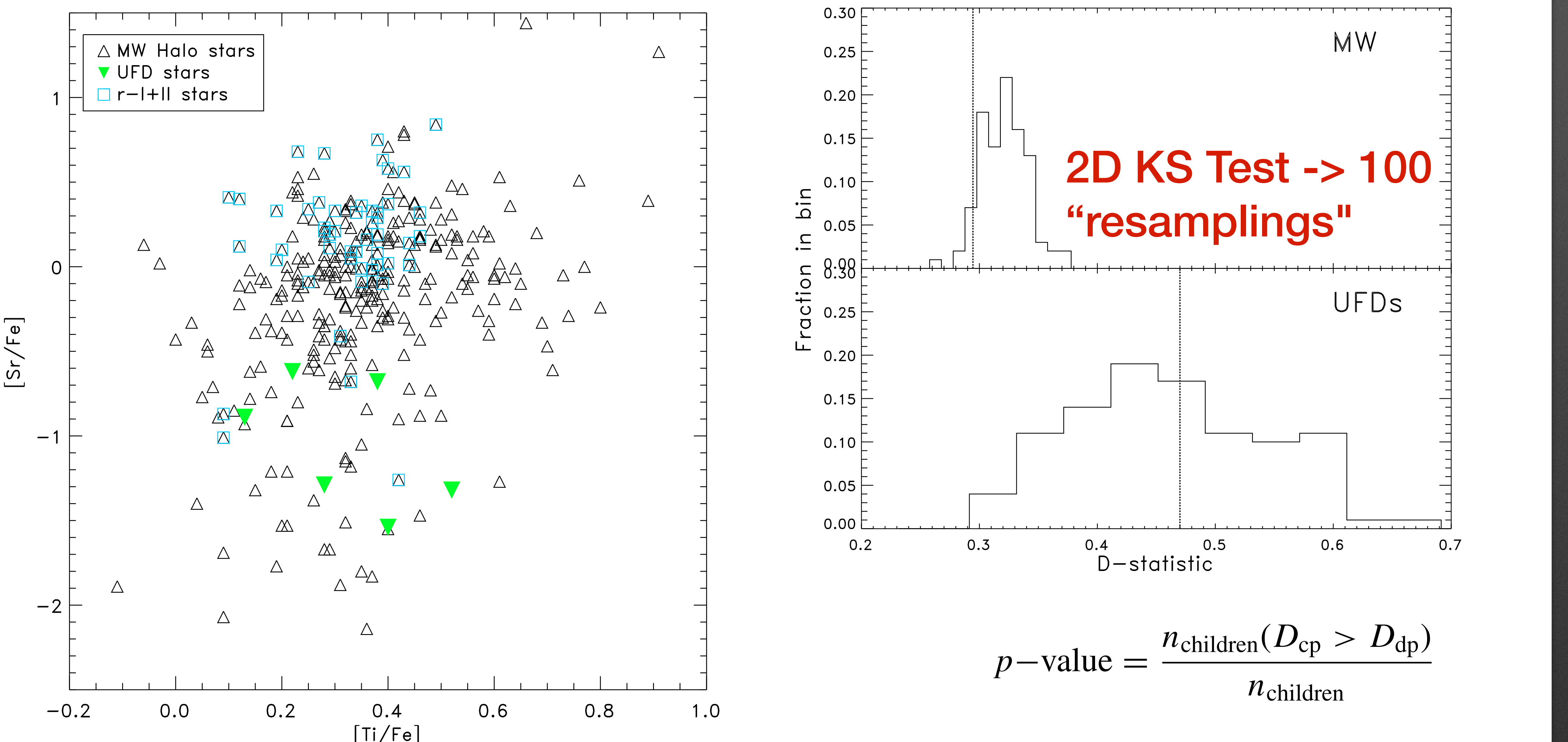

$$p\text{—value} = \frac{n_{\text{children}}(D_{\text{cp}} > D_{\text{dp}})}{n_{\text{children}}}$$

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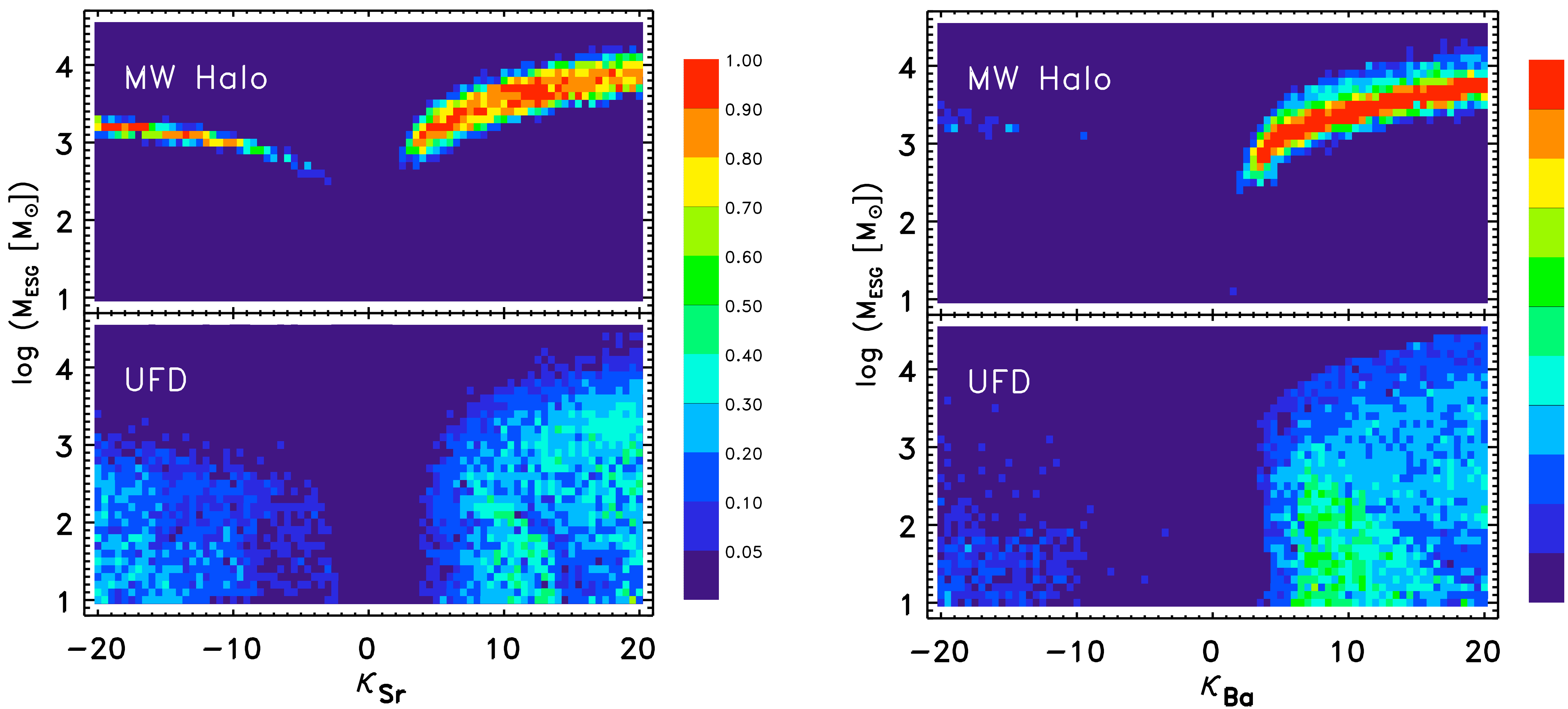

p-Value landscape as function of enriching stellar generation mass (M_ESG) and MDY strength (K_Sr, K_Ba) from MW Halo and UFD stars

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Table 1
Strength of Mass-dependent Yields

Element (neutron-capture)	Metallicity ($\log Z$)	$\kappa^{8\text{--}10\,M_\odot}_{\text{empirical}}$ (r)[a]	$\kappa^{15\text{--}40\,M_\odot}_{\text{ab initio}}$ (s)[b] (nr/rs)	$\kappa^{15\text{--}40\,M_\odot}_{\text{inferred}}$ (s)[c] (rs/ss)	This work
Strontium (Sr)	-5	~ -15 or -18	$\sim 3.3/5.8$	$\sim 6.5/6.7$	$(\lesssim -10)$, $(\gtrsim 7)$
	-3		$\sim 4.5/6.6$	$\sim 7.4/\cdots$	
Barium (Ba)	-5	~ -15	$\cdots$	$\sim 3.6/3.6$	$\sim(6\text{–}12)$
	-3		$\cdots$	$\sim 3.9/\cdots$	

Notes.
Chieffi & Limongi (2004) and Limongi & Chieffi (2012) provide another set of theoretical MDYs for Sr. From Chieffi & Limongi (2004) we find that the estimated MDYs for Sr given for progenitors with $z > 0$ to $z \simeq z_\odot$ results in strengths that are $1 \lesssim \kappa_{\text{Sr}} \lesssim 4$. The MDY for Sr for zero metallicity stars is $\kappa_{\text{Sr}} \simeq 8$—compatible with our work. However, more recent work by the same authors (Limongi & Chieffi 2012) produces a $\kappa_{\text{Sr}} \lesssim 5$ for zero metallicity stars. This result is only marginally compatible with our findings.
[a] Derived from empirical yields given in Cescutti (2012).
[b] Derived from Figure 4.14 of Frischknecht (2012) for non-rotating (nr)/rotating stars (rs). Yields for Ba were not given.
[c] Derived from Cescutti & Chiappini (2013) for rotating stars (rs) [their *as*-models]/*spinstars* (ss) [their *fs*-models].

MDYs from literature versus THIS WORK: ALL MDYs are greater in strength than the alpha-elements yields examined in this work!

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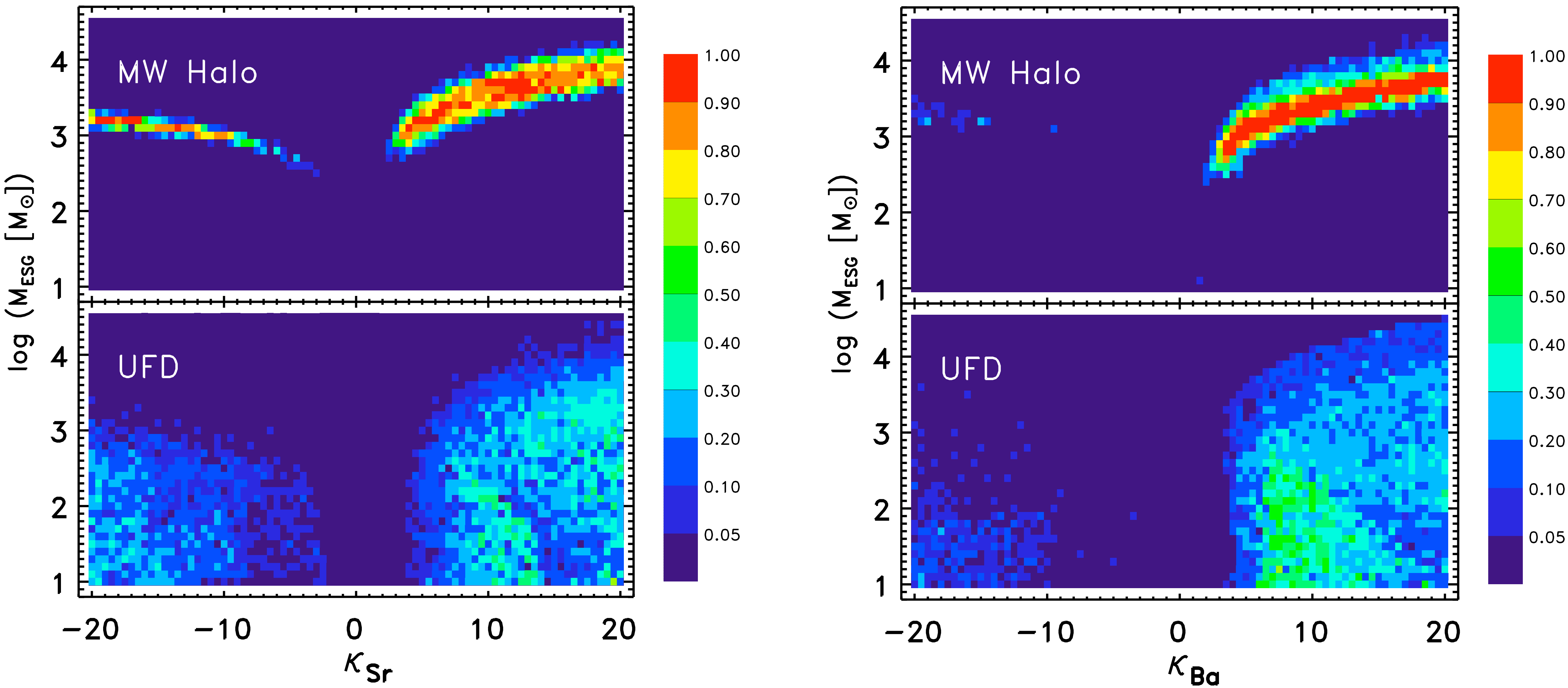
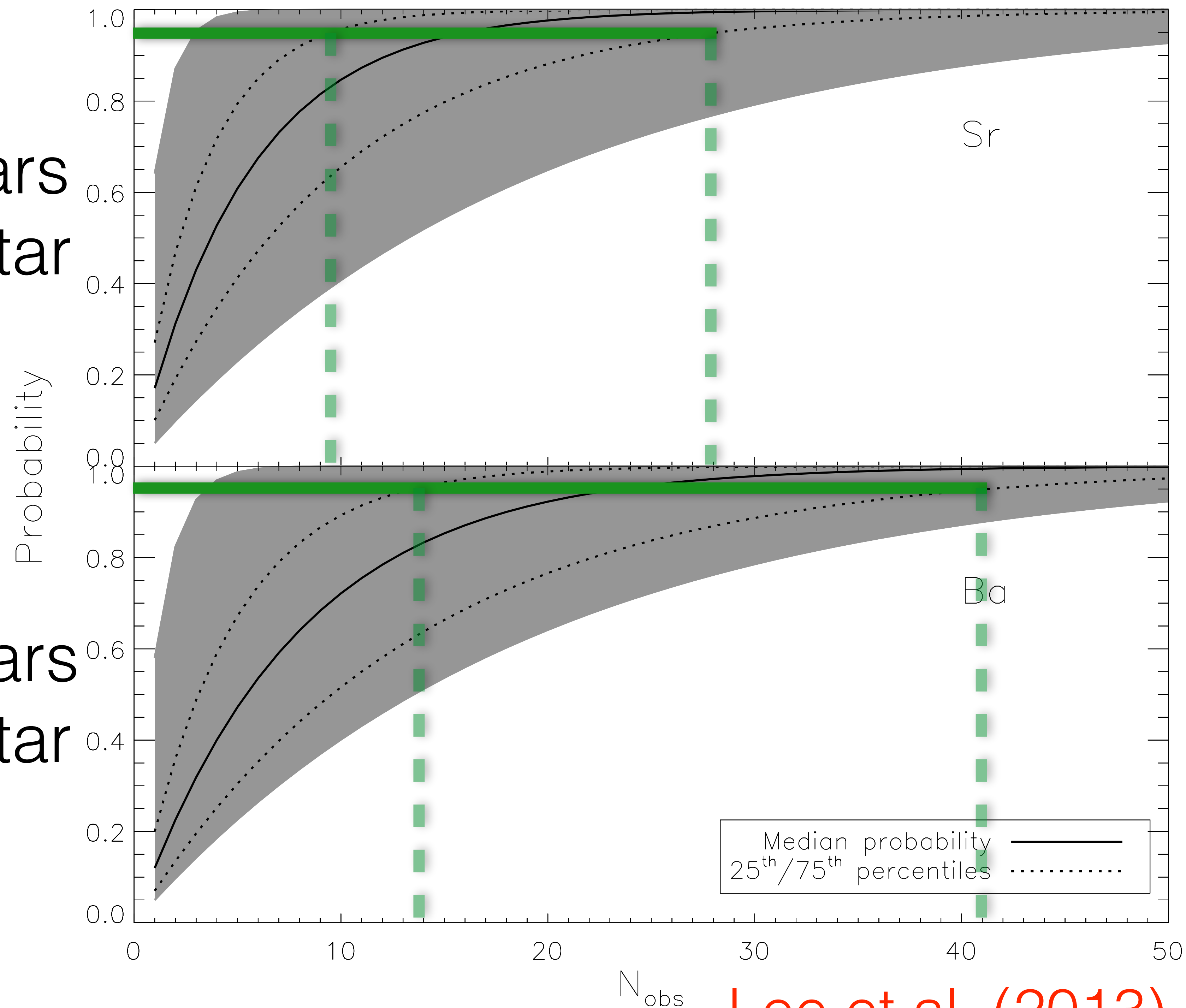


What are some observable predictions? How many stars must you observe in UFDs to find at least ONE superabundant stars in Ba or Sr?

Probability of finding [Sr,Ba/Fe] > 0 star

Sr ~15 stars w/10-28 star range

Ba ~34 stars w/14-41 star range



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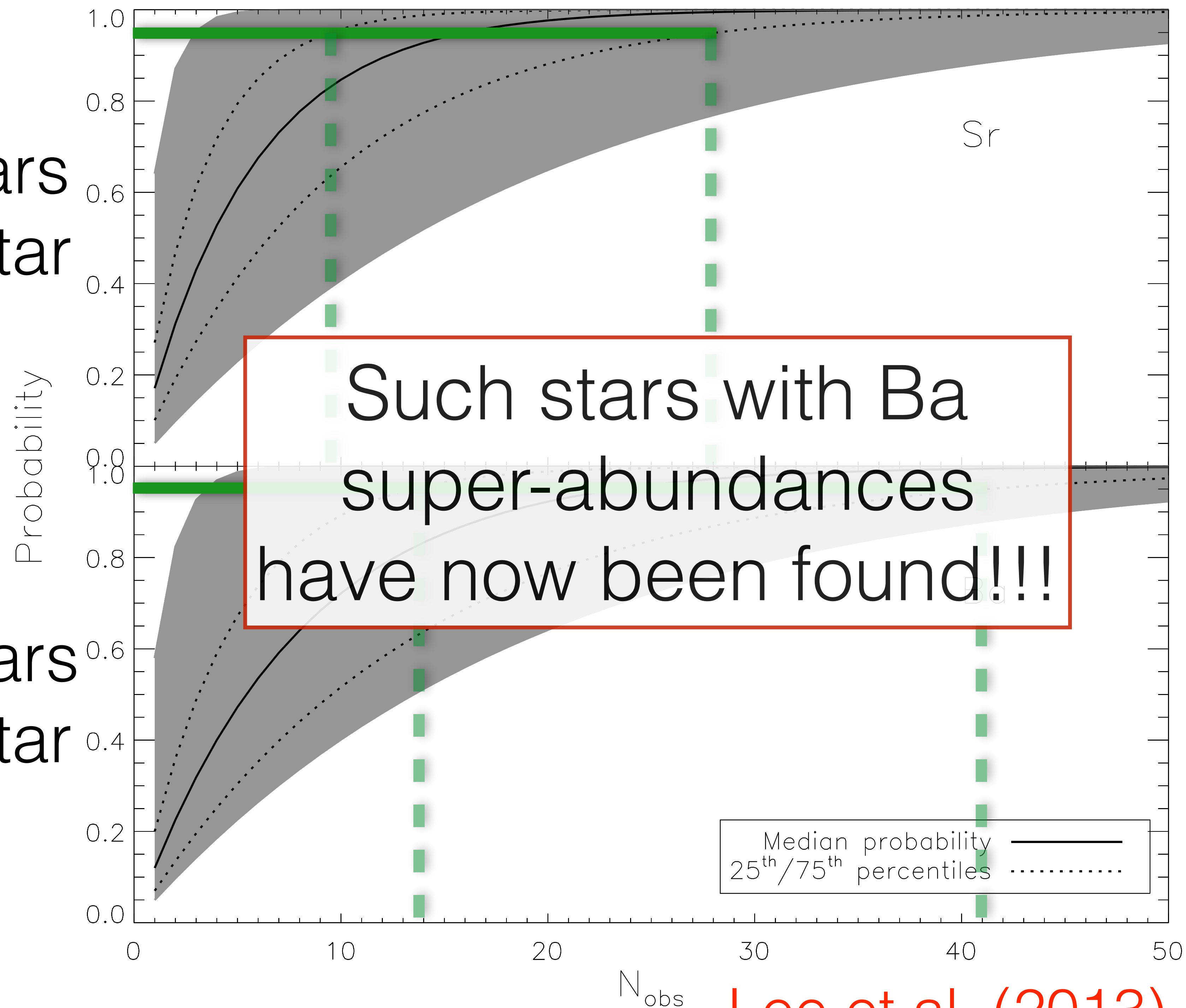

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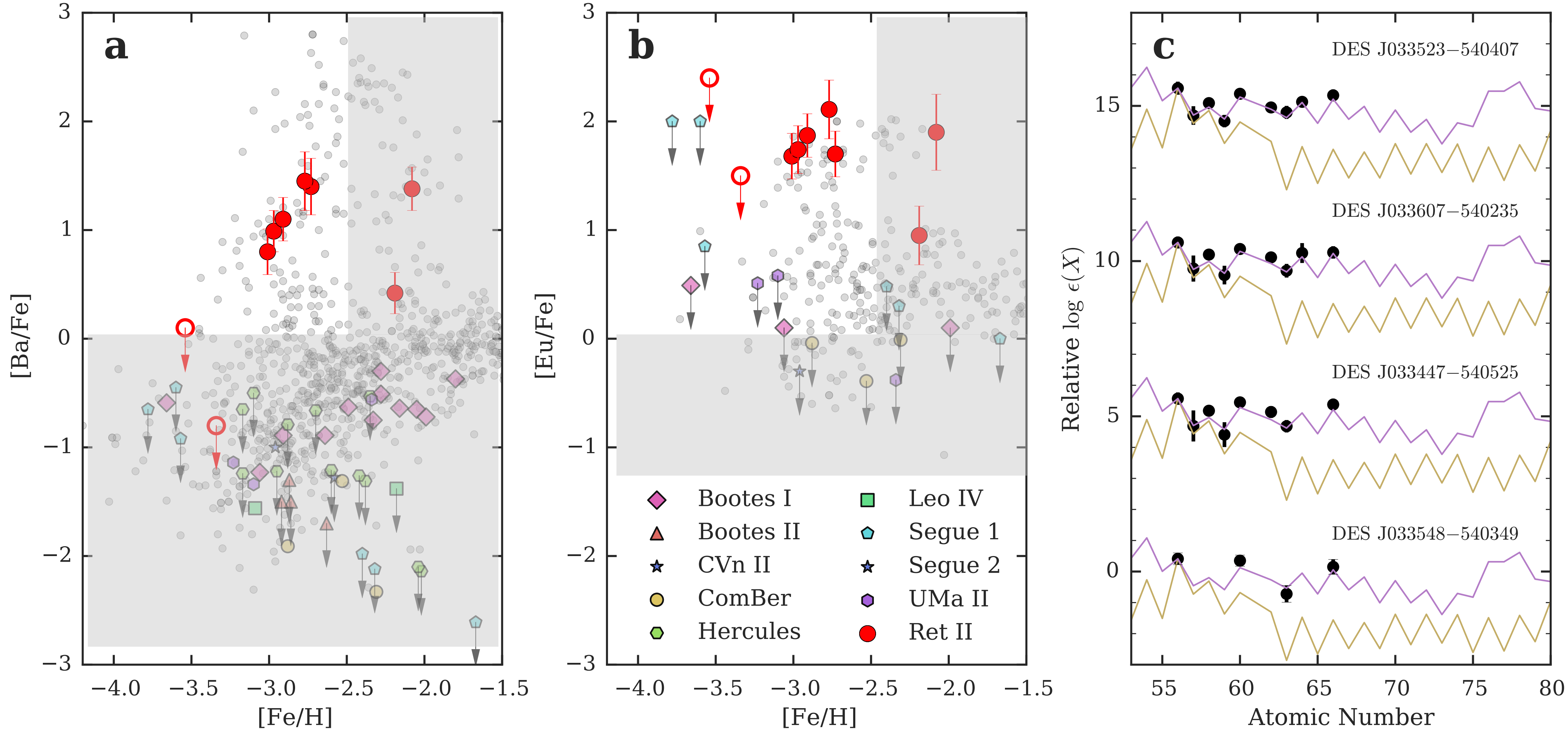

Ji et al. (Nature 2016)

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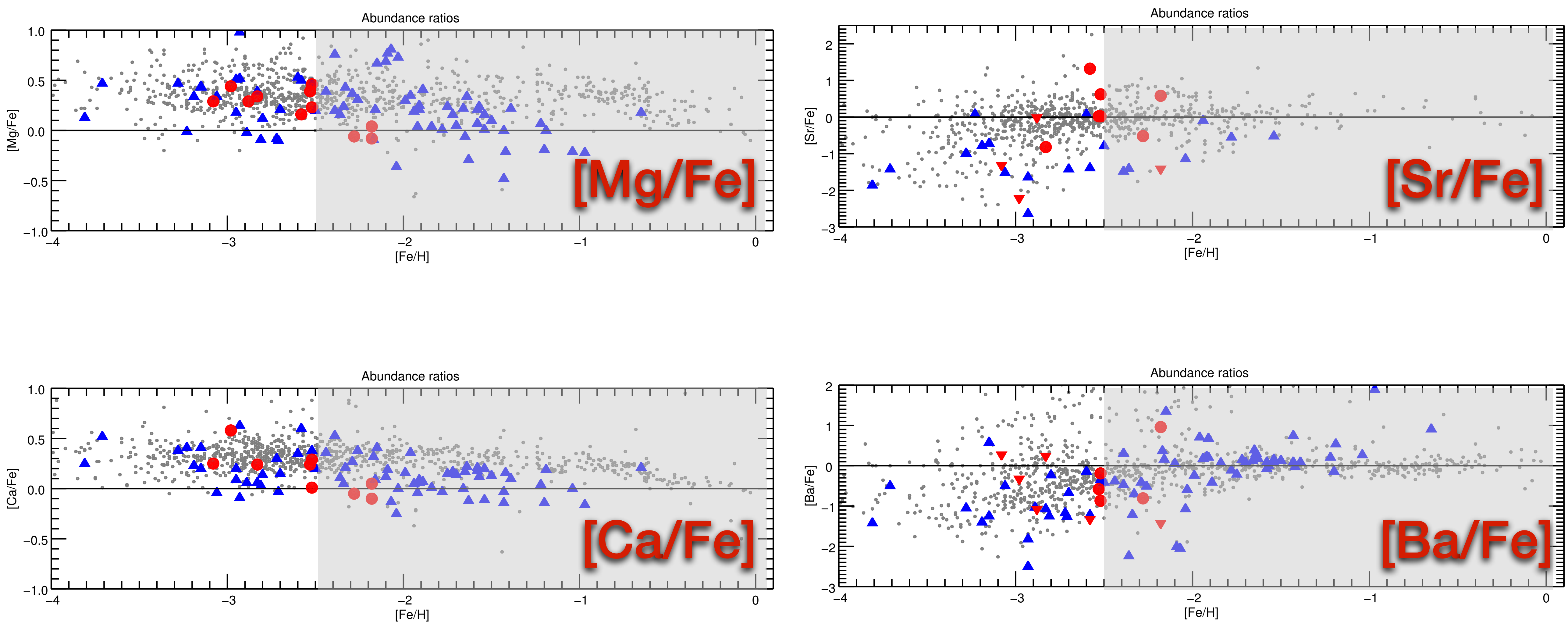

P. Francois et al. (2016)

What are some observable predictions? How many stars must you observe in UFDs to find at least ONE superabundant stars in Ba or Sr?

Future Endeavors

- Answer questions involving the r-process: what are all the significant sources for r-process elements? what is the dominant channel/source for the r-process? Is [Ba/Fe] sufficient enough to distinguish between different r-process channels or nucleosynthetic sites? What elements in general are good for disentangling nucleosynthetic enrichment sites from one another in GCE models? in observations

- Refine my statistical methods approach to maximize the return on data inference as I expand my analysis into three or more CARD dimensions

- Constrain the occurrence rate of neutron star mergers (+exotic SN) in UFDs

- Derive general analytic solutions or approximations to the PDFs for MDY functions to increase the speed of analysis

Clear Skies and Bug-less Codes!
Thank You! Questions?

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Image Credit: Nick Risinger